Washington State University

EE582 Advanced Power Electronics

Project 1

Power Factor Correction Circuits and its Feedback Controller

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1. Introduction

With the high modernization, people have a higher requirement for the power quality. Bad power quality would affect electronic devices to not work. Power factor is an important qualification for the power system. Power factor correction is very important because low power factor brings lots of problems to our circuits and power devices. In this project, we will use Matlab/Simulink to design the feedback controllers for single-phase PFC circuit.

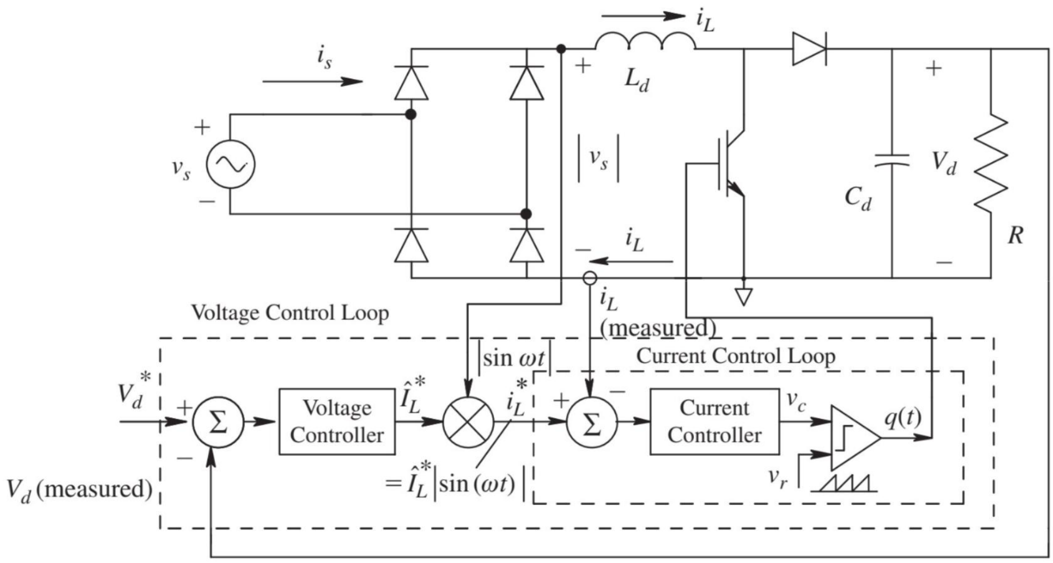

Fig. 1. Single-phase PFC circuit and feedback control.

2. Theory

The basic idea of PFC is using power conversion of high frequency switching mode to make the shape of input current close to sinusoidal wave. In most cases, the correction of power factor is achieved by an independent part which is called PFC (power factor corrector). Typical PFC is to use two cascaded loops: voltage control loop (outer loop) and current control loop (inner loop). The voltage control loop is to regulate the boost DC output voltage and provide the amplitude fir the reference to the current controller. This current always remain the residual distortion. The purpose of power factor correction is to make the input current sinusoidal as much as possible to reduce harmonic distortion and its associated losses and bring the power factor in ac circuits close to one.

3. Simulation Results (Matlab/Simulink)

Nominal input ac source voltage - 120 V
Line frequency - 60 Hz
Output voltage - 250 V
Maximum power output - 500 W

Switching frequency - 100kHz
Output filter capacitor - 200 μH
Inductor - 1.5 mH
Full-load equivalent resistance - 125 ohms

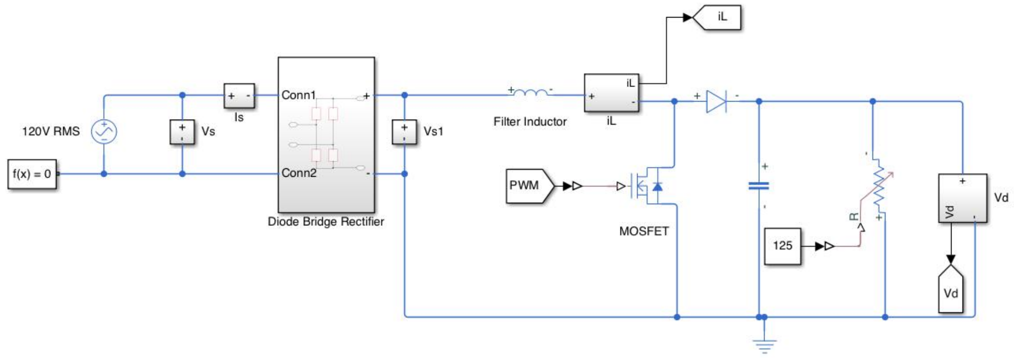

Fig. 2. Simulation of Single-phase PFC circuit.(Matlab/Simulink)

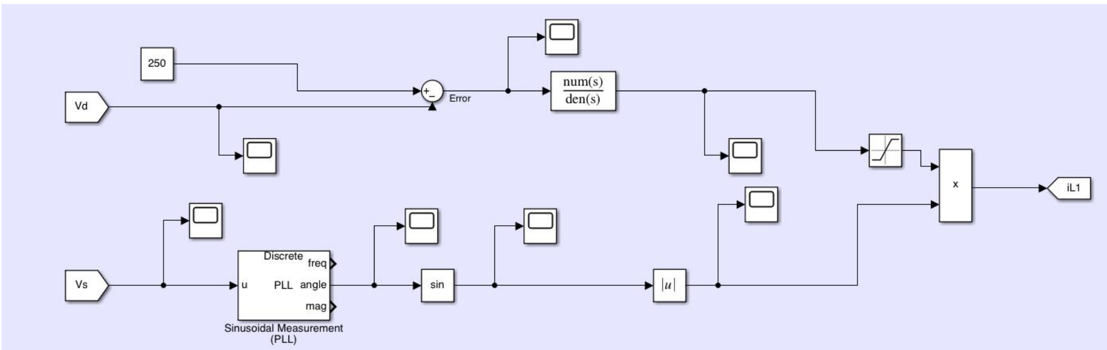

Fig. 3. Voltage Control Loop

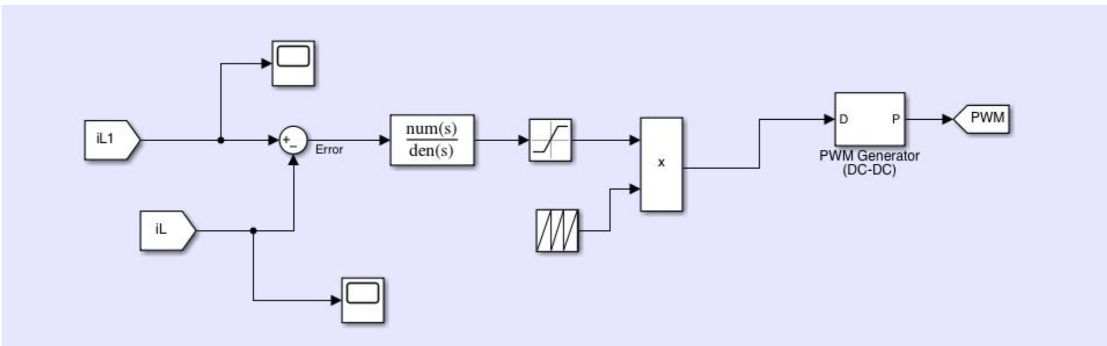

Fig. 4. Current Control Loop

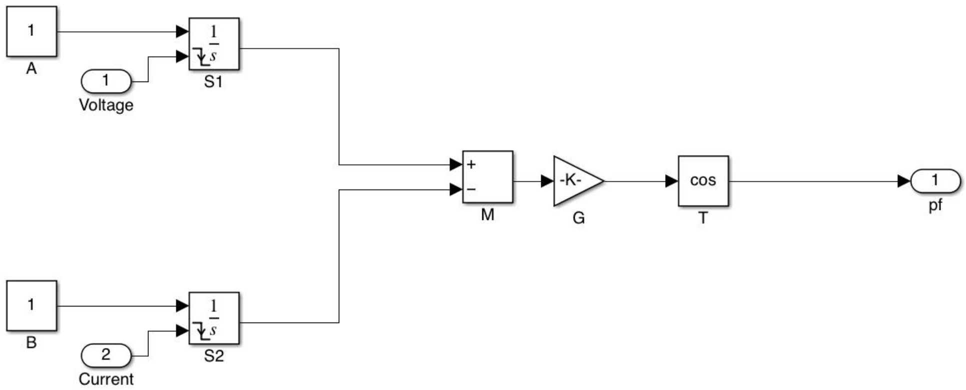

Fig. 5. The Circuit of Calculating Power Factor

Part A)

(1) Design the parameters for the inner current controller given below and show the calculation steps in detail

$$G_i(s) = \frac{k_c\ (1 + s/w_z)\hat{}2}{s\ (1 + s/w_p)\hat{}2}$$

Put the crossover frequency of the inner loop at 10 kHz and the phase margin of 60°.

$$\mathrm{GpI(s)} = \frac{V_d}{s*LD} = 0.0000\ -\ 2.6526i$$

$$W_z = 3.6276e + 04$$

$$W_p = 1.0883e + 05$$

$$\mathrm{Kc} = 7.8957e + 03$$

$$G_i(s) \approx 7895.7/s$$

(2) Design the parameters for the outer voltage controller given below and show the calculation steps in detail

$$G_v(s) = \frac{k_c\ (1 + s/w_z)}{s\ (1 + s/w_p)}$$

Put the crossover frequency of the outer loop at 60 Hz and the phase margin of 60°. Verify if the second-order harmonic (120 Hz) component in the output of the outer voltage controller can be not higher than 5% of the inductor peak current at full load condition.

If yes, keep the parameters for outer voltage controller.

If not, reduce the outer loop crossover frequency, then calculate the parameters again and show the calculation steps.

When $f_c = 60HZ$;

$$\mathrm{GpI(s)} = 0.5 * (V_{in}/V_{out}) * (R/2)/(1 + (s/1/(R * C/2))) = 0.9141\ -\ 4.3076i$$

$W_z = 144.6409$

$W_p = 982.5871$

Kc = 32.8466

Assume G'=0.05*4*2*pi*120*C*V0/Vin=0.0444;

$$G_v = Gpl(2 * pi * 120 * j) = 0.1834$$

$G_v > G'$. So that, we need to change the crossover frequency. By calculate we find as

$f_c = 27$ $G_v < G'$.

$$G_v = 0.0440$$

And

$$G_v(s) \approx (9.3282 + 0.107s)/s$$

Part B)

Develop a simulation program for the single-phase PFC. Run your simulation program for tasks given in Table 1.

1) For each of the tasks, plot waveforms (2 cycles each) for the utility voltage Vs (V) and line current Is (A) and calculate the input power factor; plot the waveform for the dc voltage Vd (V). 2) Plot the harmonic spectrum (0 to

1. Task 1

Full Load - 125 ohms

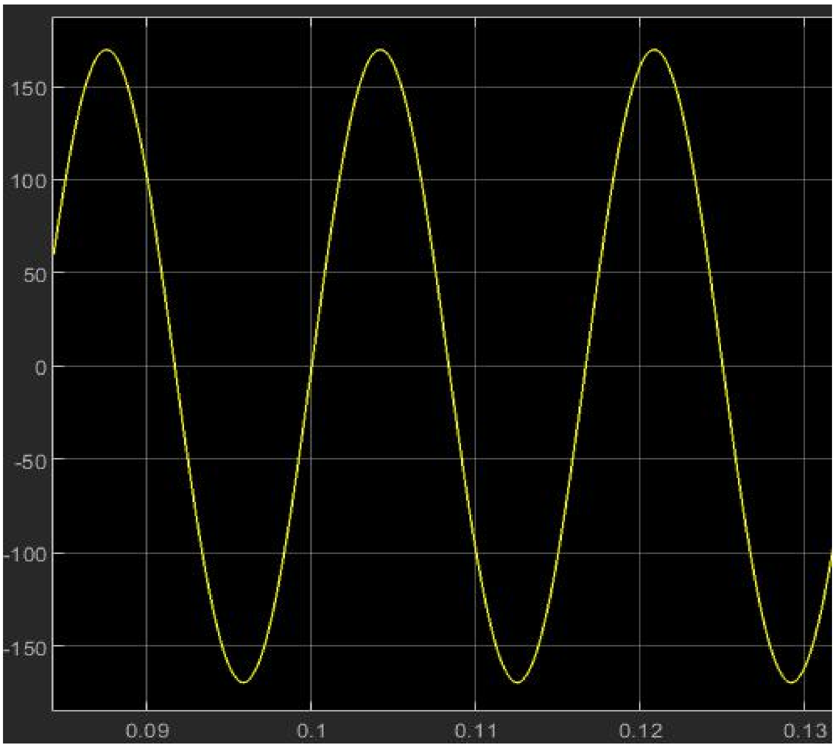

Fig. 5. Vs for Full load

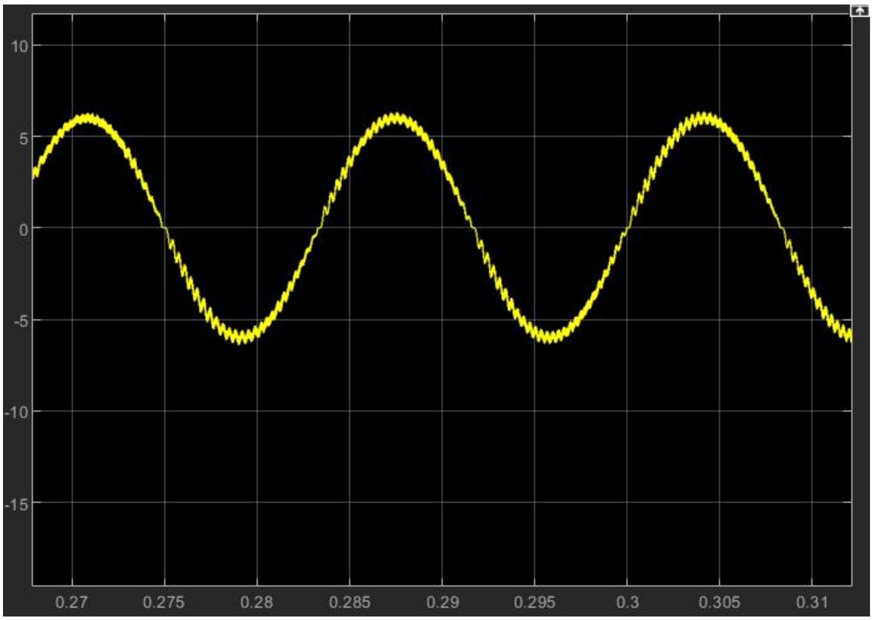

Fig. 6. Is for Full load

Power Factor=1

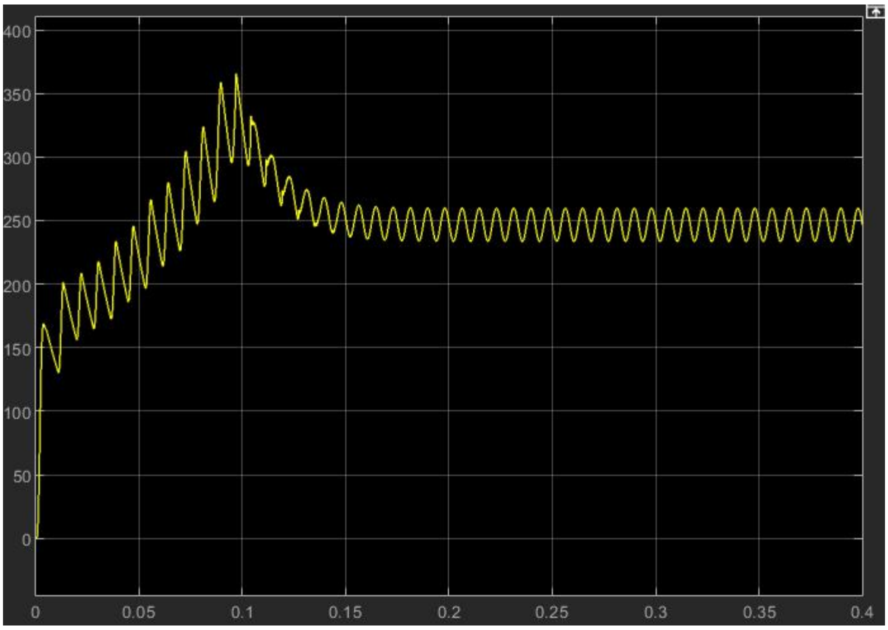

Fig. 7. Vd for Full Load

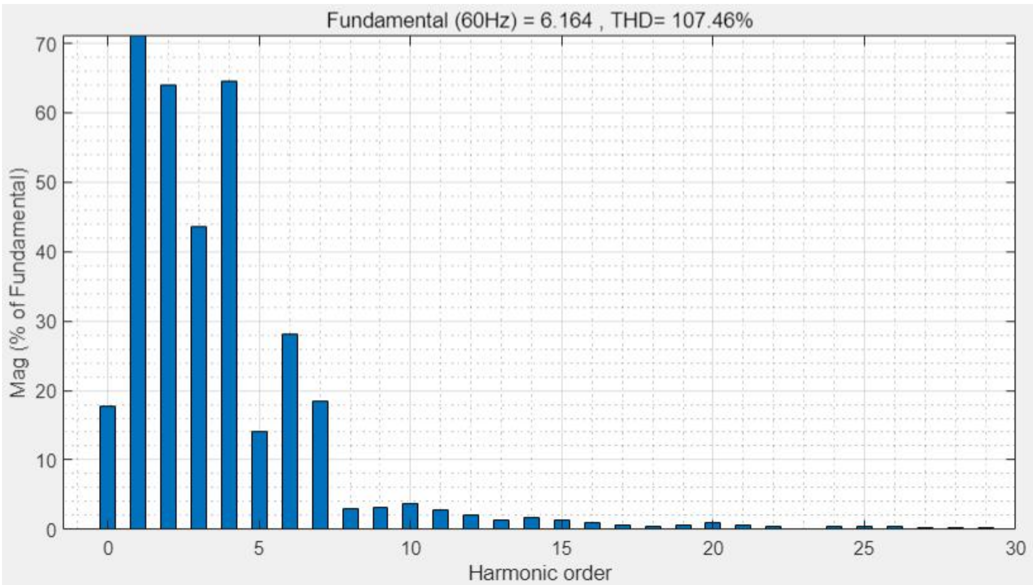

Fig. 8. The harmonic spectrum of Is

THD of Is =107.46%

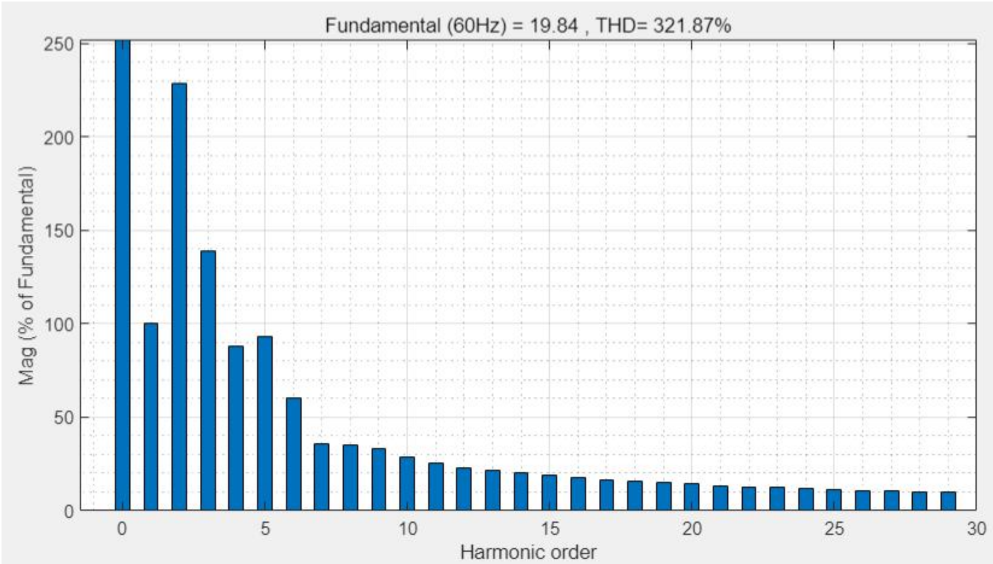

Fig. 9. The harmonic spectrum of Vd

2.Task 2

Half Load - 250 ohms

$$G_v(s) \approx (6.1054 + 0.0955s)/s$$

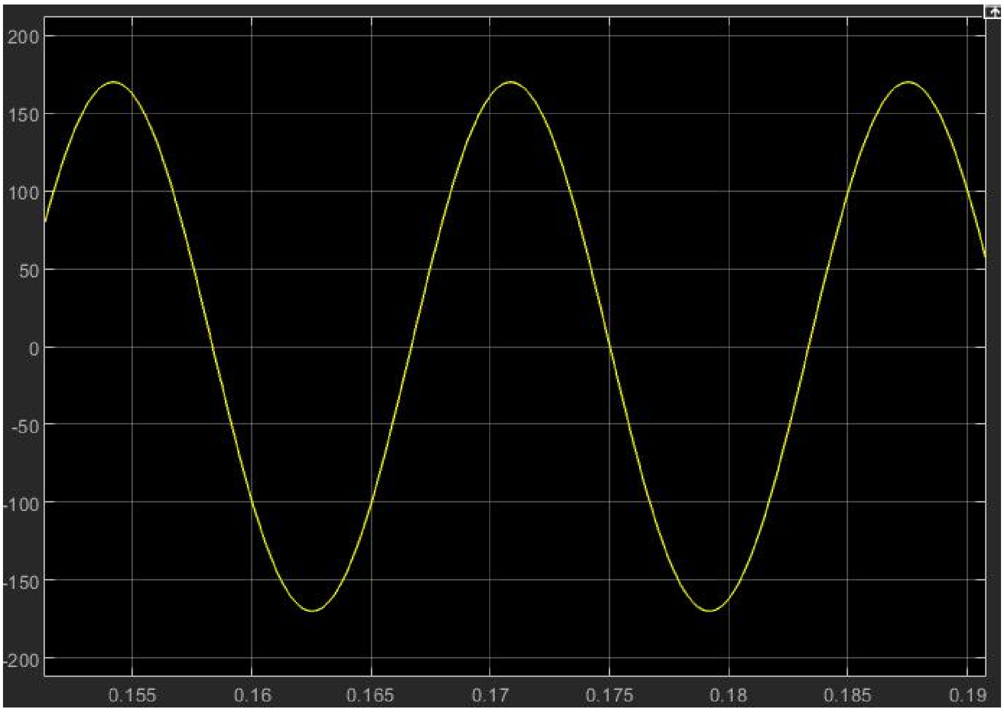

Fig. 10. Vs for Half load

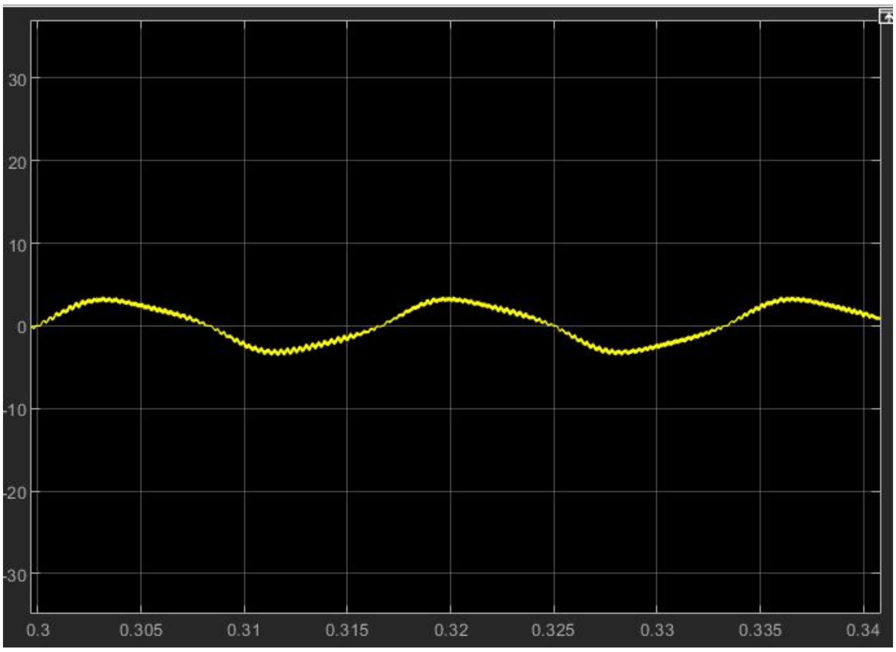

Fig. 11. Is for Half load

Power Factor=1

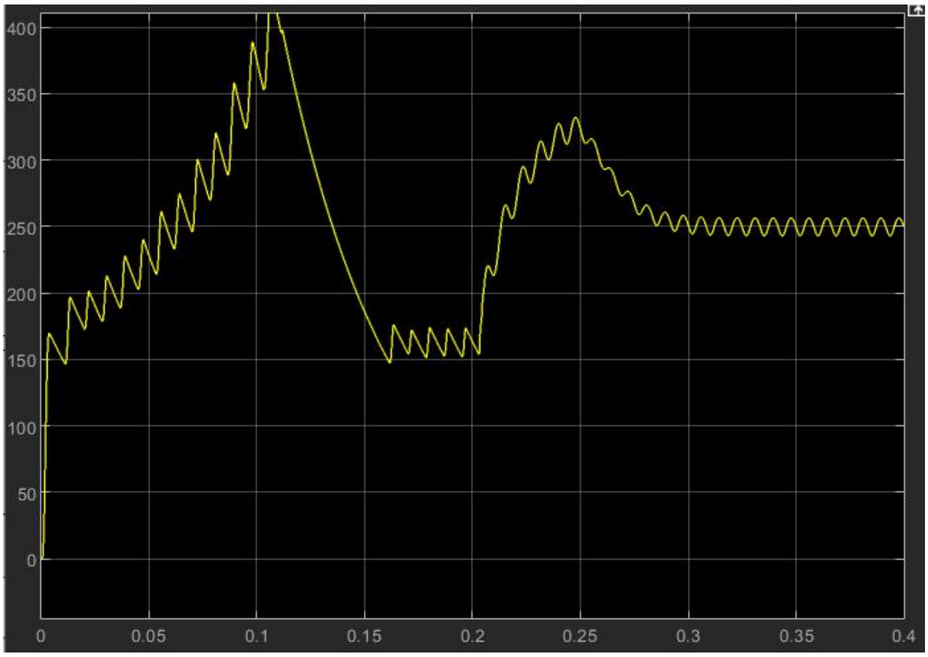

Fig. 12. Vd for Half load

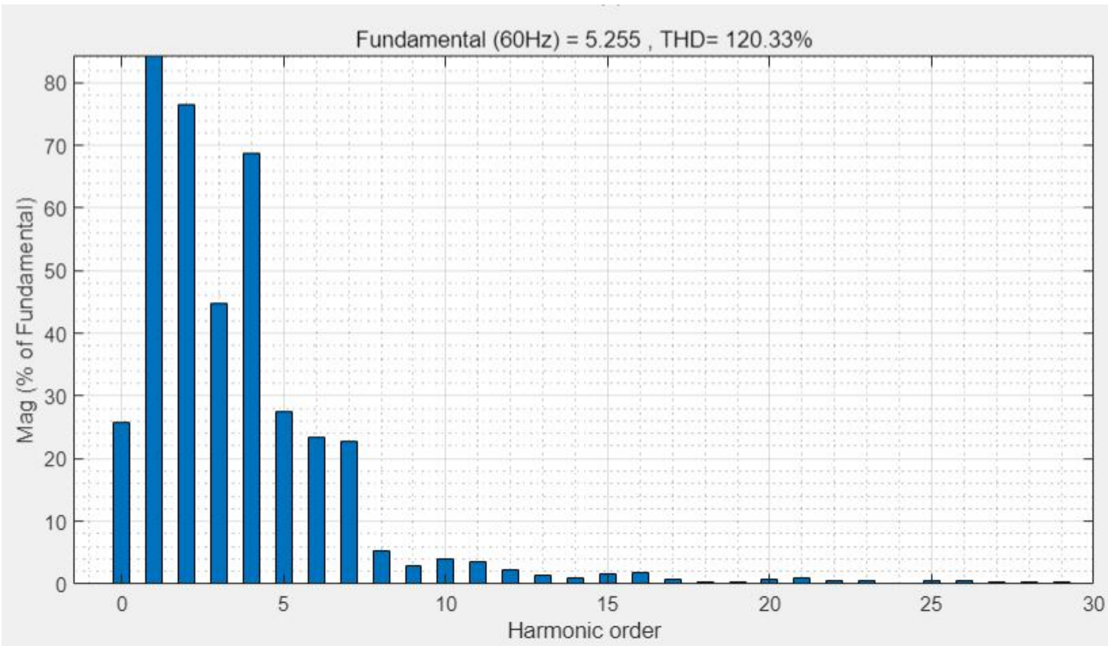

Fig. 13. The harmonic spectrum of Is
THD of Is = 120.33%

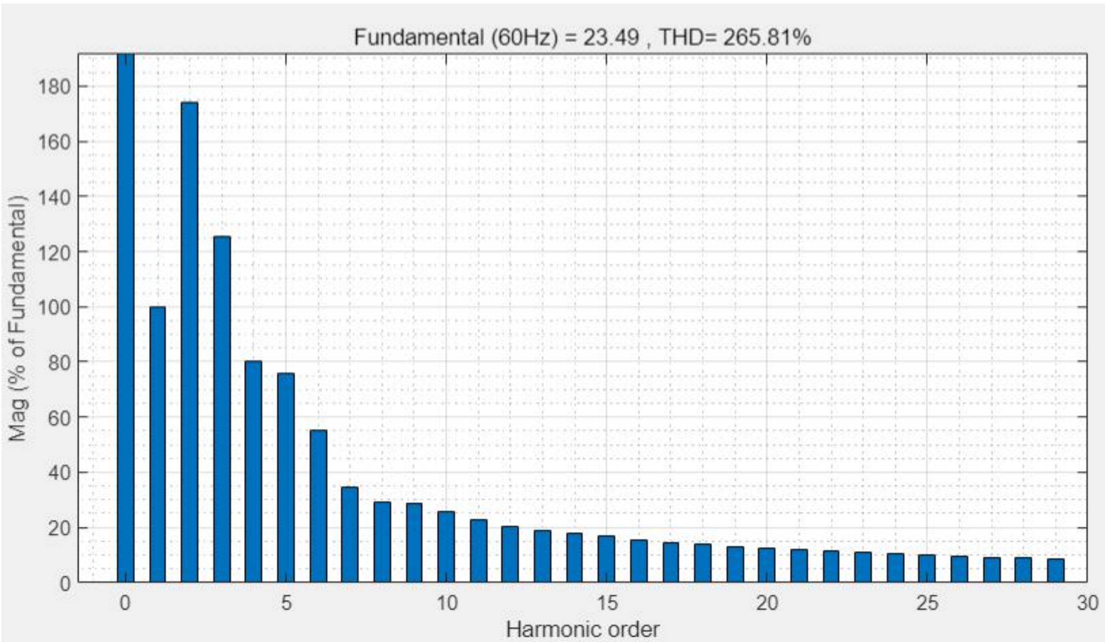

Fig. 14. The harmonic spectrum of Vd

3. Task 3

A Quarter Load - 500 ohms

$$G_v(s) \approx (4.263 + 0.086s)/s$$

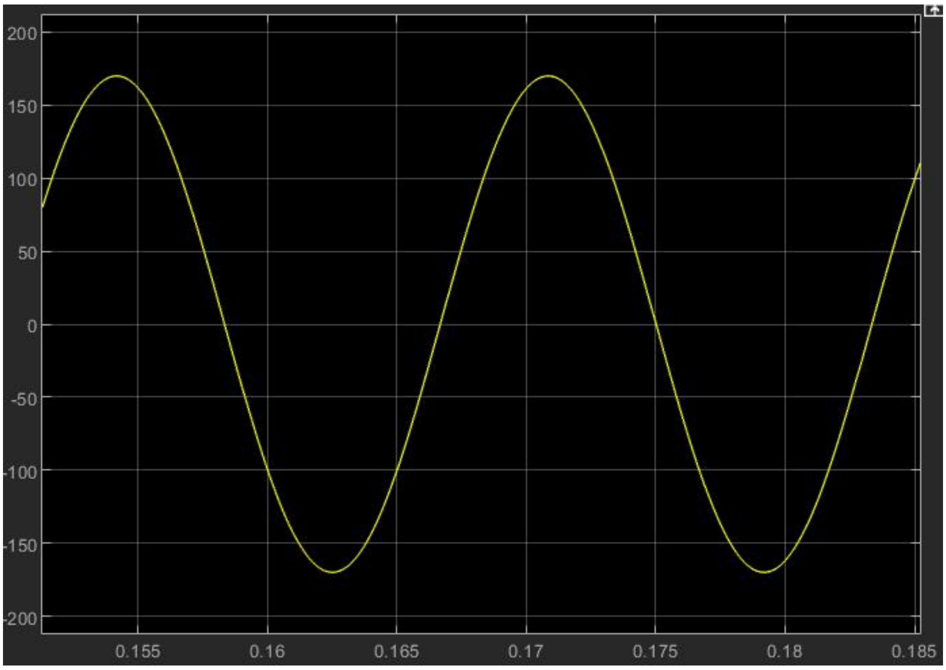

Fig. 15. Vs for A quarter load

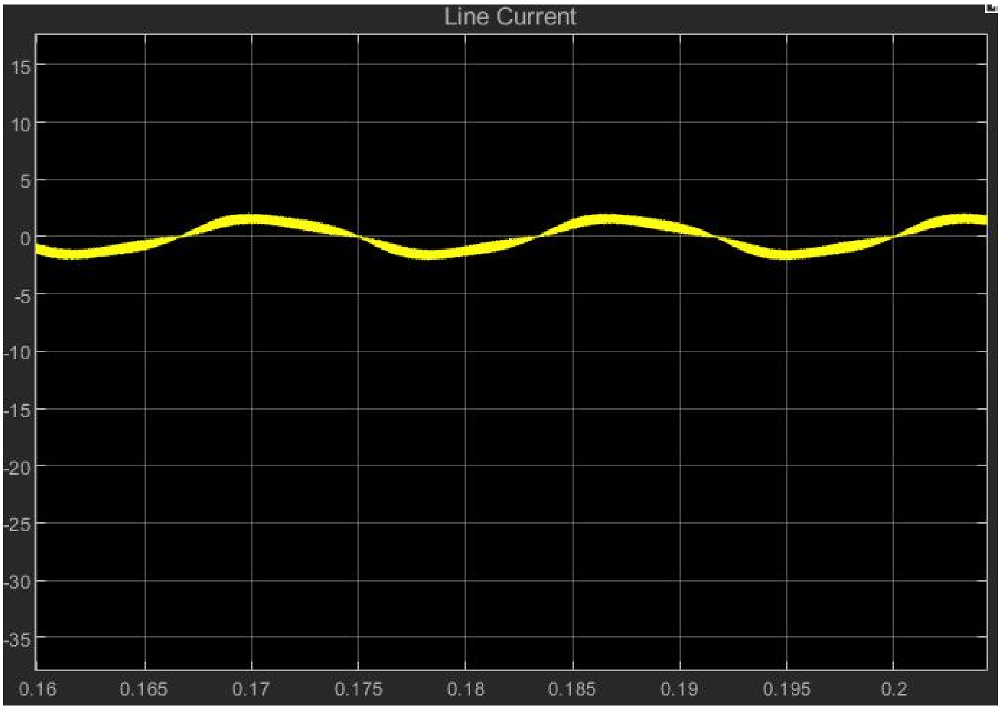

Fig. 16. Is for A quarter load

Power Factor=1

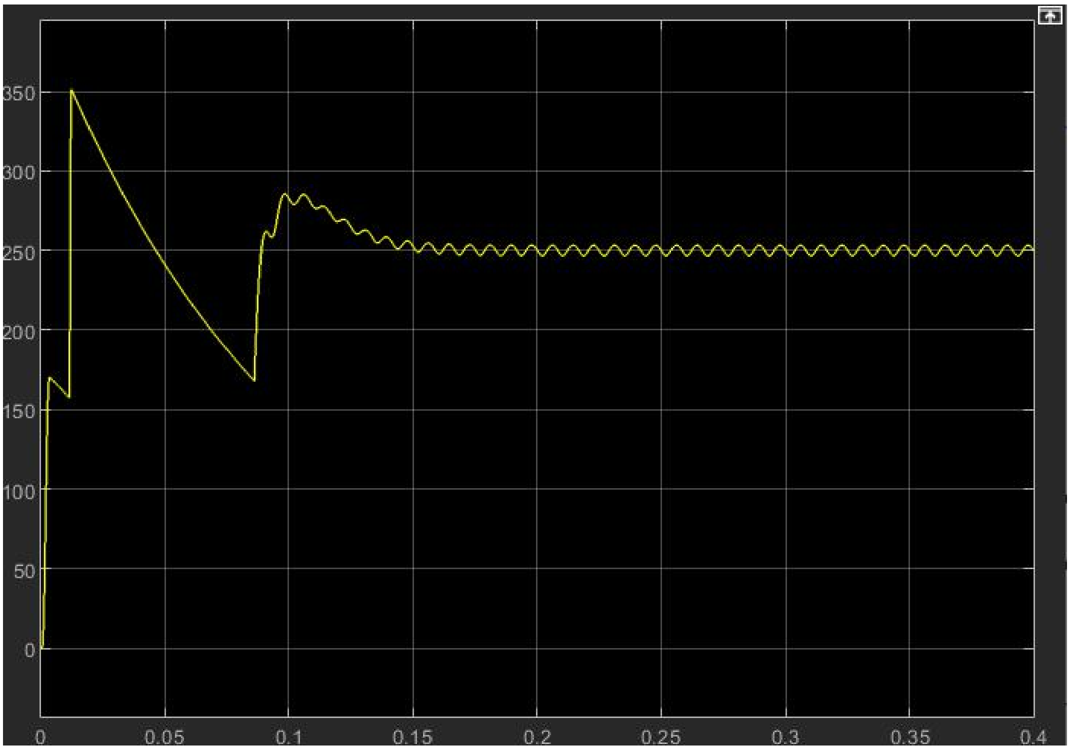

Fig. 17. Vd for A quarter load

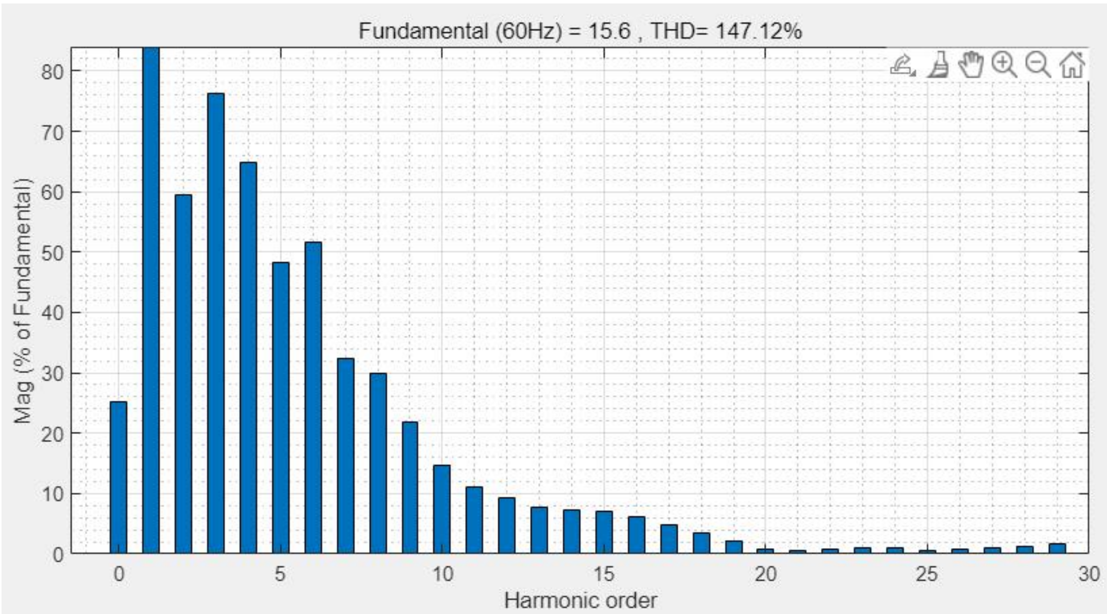

Fig. 18. The harmonic spectrum of Is

THD of Is = 147.12%

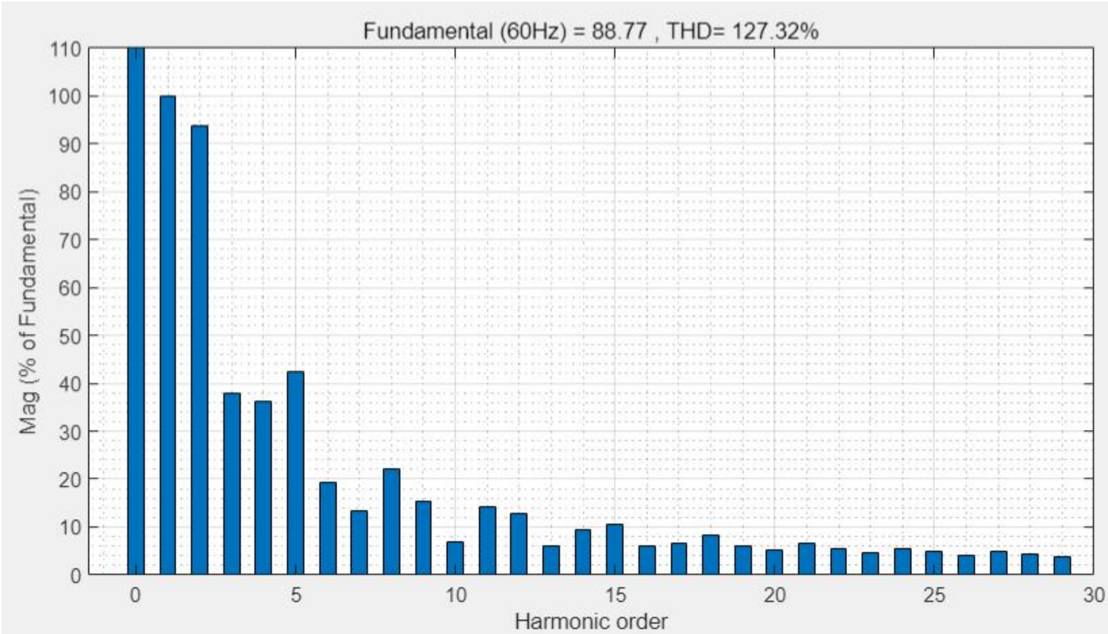

Fig. 19. The harmonic spectrum of Vd

2) Analysis

As we can see from the image, the output voltage rises quickly at the beginning, and the distortion signal appears for a short time. Through our control of the circuit, this value is quickly limited, and the output voltage and current both tend to the expected value. From our power Factor measurements, PF is always 1. With the increase of load resistance, THD of current is become greater.

Part C)

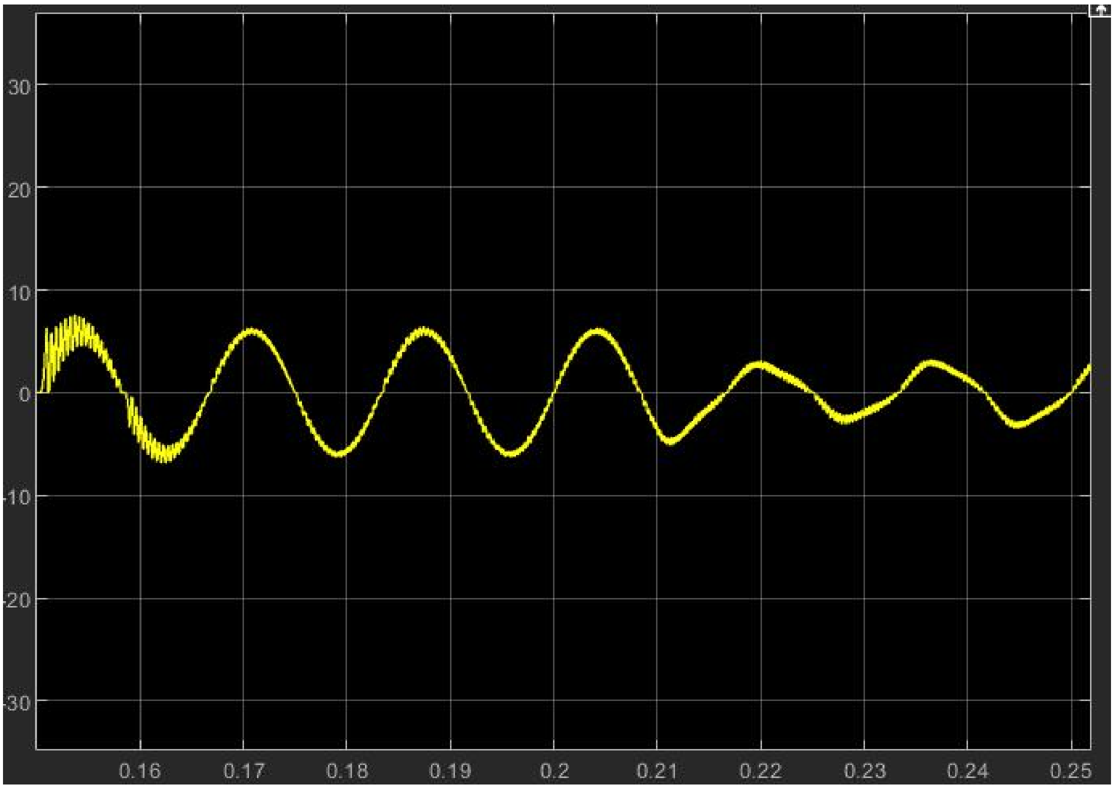
30
20
10
0
-10
-20
-30
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24
0.25

Fig. Is

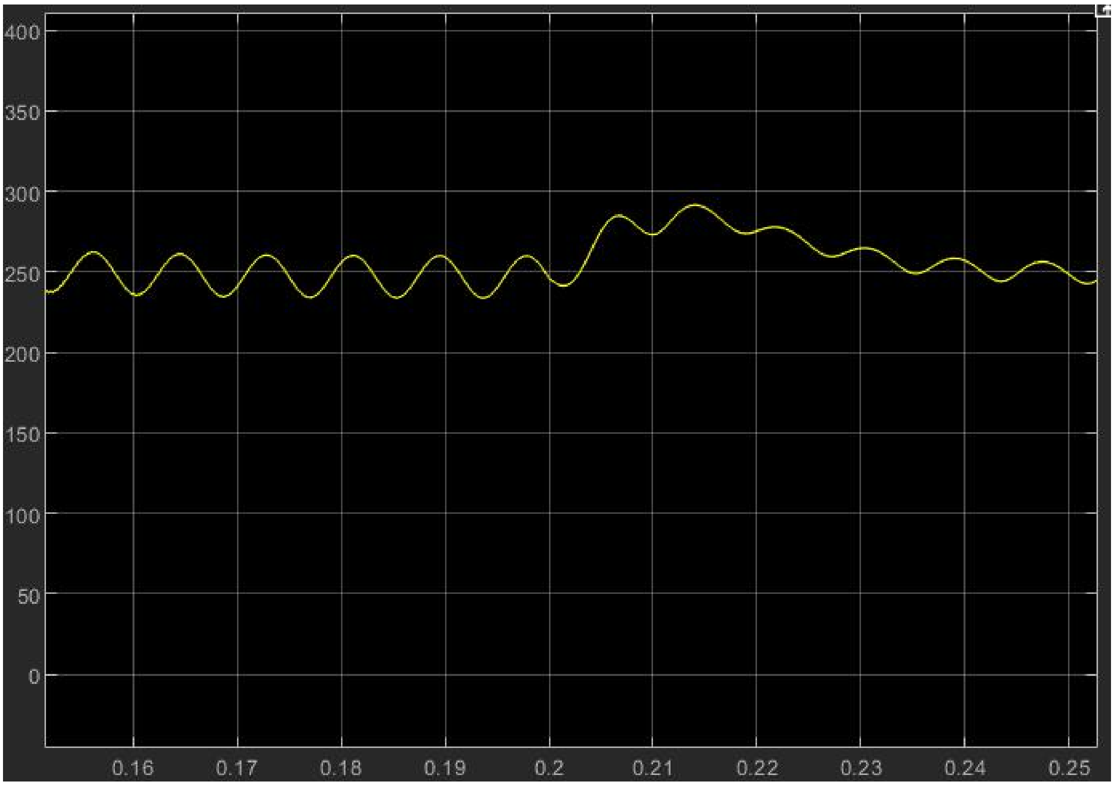
400
350
300
250
200
150
100
50
0
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24
0.25

Fig. Vd

4. Conclusion

The purpose of the power factor correction circuit is to increase the conduction Angle of the rectifier so that the ac input current waveform is sinusoidal and in phase with the voltage waveform. In this project, I successfully use the feedback controller to control the circuit, and I can keep the steady of voltage an current. But there's only one downside that I can not use the max power to limit the circuit. Actually, I tried many different ways to limit the circuit, including the limit of inductance current and the limit of current output. I think maybe I still don't know how to use this knowledge. In the future, I will continue to focus on the resolution of this issue.